Figure 3.1 The generic circuit element.

Current flows through circuit elements, such as that depicted in Figure 3.1, and through conductors, which we indicate by lines in circuit diagrams. For every circuit element we define a voltage and a current. The element has a v-i relation defined by the element's physical properties. In defining the v-i relation, we have the convention that positive current flows from positive to negative voltage drop. Voltage has units of volts, and both the unit and the quantity are named for Volta. Current has units of amperes, and is named for the French physicist Ampere.

Voltages and currents also carry **power**. Again using the convention shown in Figure 3.1 (Generic Circuit Element) for circuit elements, the **instantaneous power** at each moment of time consumed by the element is given by the product of the voltage and current.

$$p(t) = v(t)i(t)$$

A positive value for power indicates that at time t the circuit element is **consuming** power; a negative value means it is **producing** power. With voltage expressed in volts and current in amperes, power defined this way has units of watts. Just as in all areas of physics and chemistry, power is the rate at which energy is consumed or produced. Consequently, energy is the integral of power.

$$E(t) = \int_{-\infty}^{t} p(\alpha)d\alpha$$

Again, positive energy corresponds to consumed energy and negative energy corresponds to energy produc tion. Note that a circuit element having a power profile that is both positive and negative over some time interval could consume or produce energy according to the sign of the integral of power. The units of energy are **joules** since a watt equals joules/second.

Exercise 3.1.1

Residential energy bills typically state a home's energy usage in kilowatt‒hours. Is this really a unit of energy? If so, how many joules equals one kilowatt‒hour?

3.2 Ideal Circuit Elements

The elementary circuit elements the resistor, capacitor, and inductor impose **linear** relationships between voltage and current.